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Burr size reduction in drilling by ultrasonic assistance

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Abstract

Accuracy and surface finish play an important role in modern industry. Undesired projections of materials, known as burrs, reduce the part quality and negatively affect the assembly process. A recent and promising method for reducing burr size in metal cutting is the use of ultrasonic assistance, where high-frequency and low-amplitude vibrations are added in the feed direction during cutting. Note that this cutting process is distinct from ultrasonic machining. This paper presents the design of an ultrasonically vibrated workpiece holder, and a two-stage experimental investigation of ultrasonically assisted drilling of A1100-0 aluminum workpieces. The results of 175 drilling experiments with uncoated and TiN-coated drills are reported and analyzed. The effect of ultrasonic assistance on burr size, chip formation, thrust forces and tool wear is studied. The results demonstrate that under suitable ultrasonic vibration conditions, the burr height and width can be reduced in comparison to conventional drilling.

Keywords: Burr; Drilling; Metal cutting; Ultrasonic assistance; Ultrasonic assisted drilling; Vibration assisted drilling

1. Introduction

Conventional metal cutting methods produce undesired projections of material that result from plastic deformation, known as burrs. Burrs reduce the accuracy of the parts and subsequent assembly processes. Typically deburring accounts for up to 25% of the total production cost [1]. To reduce or even eliminate the deburring effort, the burr size must be reduced. In this paper, burr size reduction in drilling will be considered.

There are various methods to reduce the burr size. These include altering the cutting conditions and using suitable type of coolant. Dornfeld and Ko [2] showed that the influence of feedrate on burr size is not linear, and is dependent on other cutting conditions and on the material being machined. Varying the feedrate during drilling can also reduce burr size [3]. Special drill geometry, such as radial periphery drills, can produce smaller burrs than standard drills [4]. However, these special drill geometries are often expensive to manufacture. Using suitable coolant and tool coating to reduce the friction between the tool and the workpiece was found to produce smaller burrs [3]. However, coolants are expensive, hazardous to worker health, and pollute the environment. Kim et al. [5] have developed an empirical drilling chart to choose suitable cutting condition for different materials in order to reduce burr size. However, these drilling charts are only applicable to limited ranges of drilling. Drilling with a backup material can also reduce burr size [6]. However, this technique cannot be applied when the exit surface of the workpiece is not accessible.

A recent and promising technique to reduce burr size is known as ultrasonic-assisted (UA) drilling. The principle of this technique is adding high-frequency (1–200 kHz) and low peak-to-peak (pk–pk) vibration magnitude (2–26 μm) in the feed direction to the tool or workpiece. This cutting process is distinct from ultrasonic drilling. Ultrasonic drilling, also known as rotary ultrasonic machining, is a specific class of ultrasonic machining. Ultrasonic machining is a machining process where a tool is vibrated ultrasonically and feed axially

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into the work material. Abrasive slurry is fed between the vibrating tool and the work material, resulting in material removal by brittle fracture. This brittle fracture is caused by the impacts between the abrasive and the work material that are induced by the vibrating tool. Ultrasonic drilling is an ultrasonic machining process with a rotating cylindrical tool. The rotation of the tool enhances the abrasive process. Ultrasonic drilling has only been applied to brittle materials. On the other hand, UA drilling is a hybrid process of conventional drilling and ultrasonic oscillation. It is applicable to both ductile and brittle materials. The goal of this machining process is to reduce burr size and thrust force.

Takeyama and Kato [4] have experimentally shown that burr size reduction in drilling aluminum is possible with UA drilling. Zhang et al. [7] theoretically and experimentally concluded that there exists an optimal vibration condition such that the thrust force and torque are minimized, which results in smaller burrs. Clearly, more work is required to understand the effect of vibration condition on burr size.

This paper presents a two-stage experimental investigation of UA drilling of aluminum in terms of burr size reduction. In the first stage, the effect of vibration frequency, pk–pk vibration magnitude, spindle speed, feedrate, and drill diameter on burr size are investigated; in the second stage, the use of coated drills for tool wear reduction is studied. In Section 2, the designs of the actuated workpiece holder and drive circuit are presented. In Section 3 the experimental investigations are presented. Conclusions are given in Section 4.

2. Design of actuated workpiece holder and drive circuit

In order to study UA drilling, an actuated workpiece holder and a drive circuit has been designed and built. The workpiece holder consists of a piezoelectric stack actuator, a preloading mechanism, an aluminum fixture, a stainless steel-shell and a base plate (See Fig. 1).

The desired vibration conditions were chosen to be 20 kHz and 4 μm pk–pk. The actuator must be capable of producing sufficient force to drive the combined mass of the diaphragm, workpiece holder and the workpiece at this condition. The vibration of the combined mass can be modeled by simple harmonic motion. Fig. 2 shows the free body diagram of the combined mass. The vibration displacement $X(t)$, velocity $V(t)$ and acceleration $a(t)$ of the combined mass is:

$$X(t) = A_u \sin(2\pi f_u t), \tag{1}$$

$$V(t) = \dot{X}(t) = 2\pi f_u A_u \cos(2\pi f_u t), \tag{2}$$

$$a(t) = \ddot{X}(t) = -4\pi^2 f_u^2 A_u \sin(2\pi f_u t). \tag{3}$$

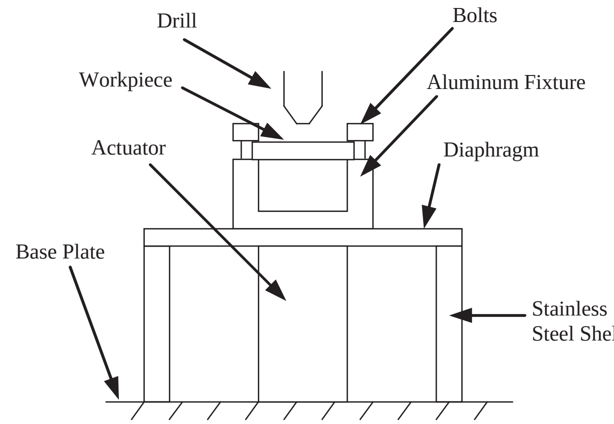

Fig. 1. Cross section of the workpiece holder.

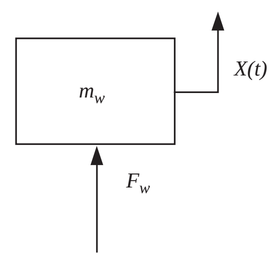

Fig. 2. Free body diagram of the combined mass.

Table 1
Required specification of the actuator

Frequency range	Displacement range	Force delivery
0–20 kHz	0–4 μm	3.2 kN

In Eqs. (1)–(3), A_u is the vibration amplitude (half of the pk–pk vibration magnitude) and f_u is the vibration frequency. Hence, the force F_w required to drive the combined mass m_w and the corresponding maximum force magnitude $F_{w\mathrm{MAX}}$ is given by

$$F_w = m_w a(t) = -4\pi^2 f_u^2 m_w A_u \sin(2\pi f_u t), \tag{4}$$

$$F_{w\mathrm{MAX}} = 4\pi^2 f_u^2 m_w A_u. \tag{5}$$

The maximum weight of the workpiece was chosen to be 10 g, and the mass of the combined mass was chosen to be 100 g in the design criteria. The required specification of the actuator can then be defined as in Table 1.

A stack actuator manufactured by Sensor Tech. Ltd. (BM532 series with 33 layers of piezoelectric disks) was chosen. The specifications of the actuator are summarized in Table 2.

The chosen actuator requires a drive voltage of 200 V pk–pk to produce its maximum displacement. The power requirement can be computed by first considering the required charging current of the actuator. In general, a piezoelectric actuator can be electrically modeled